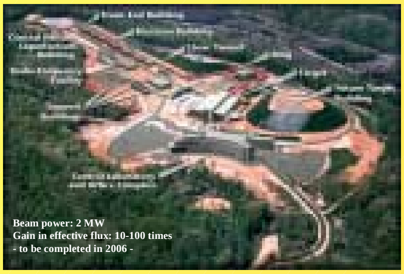
Flux gain for a next-generation neutron reflectometer resulting from improved supermirror performance

Christine Rehm*, Michael Agamalian**

Oak Ridge National Laboratory, SNS Project

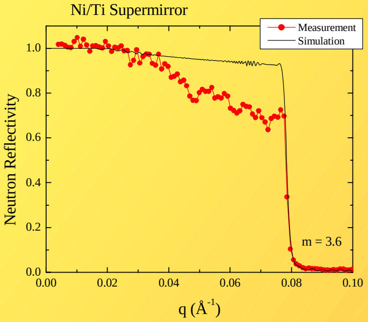
We have theoretically analyzed the intensity gain that may be achievable for the SNS Magnetism Reflectometer by increasing the performance of its supermirror guides.

The Spallation Neutron Source SNS



The Spallation Neutron Source SNS, currently under construction at Oak Ridge National Laboratory, will generate an effective neutron flux about one order of magnitude higher than the best existing neutron sources. Combined with further approaches to gain intensity by optimization of neutron optical components, development of new optical devices, and implementation of advanced instrument design, an additional increase in flux by up to one order of magnitude should result for particular SNS scattering instruments. The total intensity gain for SNS instruments, therefore, can be as high as two orders of magnitude, which will greatly enhance the quality of neutron scattering studies.

High-m supermirror imperfections

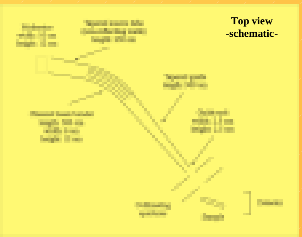


A general drawback of high-m supermirrors is that their reflectivity is far from being perfect. In large-scale production of m=3.6 supermirrors, for example, typical reflectivities of R=0.6-0.7 are reached at q_c (cf. red curve = measured data). Theoretically, assuming a perfect layering, the reflectivity function should be considerably higher, on the order of 90% (cf. black curve = simulation).

Major distortions to the reflectivity may also result from limited coherence due to deviations from the design layer thicknesses. It seems to be quite a challenge to keep the positions of the interfaces close to the nominal values in order to maintain coherent interference, particularly for supermirrors with very high m-values and the corresponding small individual layer thicknesses. For example, in the case of m=3.6, about 26 coherently reflecting bilayers are required for optimum reflectivity at q_c (where the individual layer thicknesses are about 40 Å).

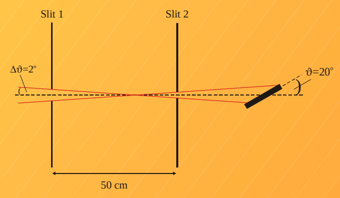
Reasons for low reflectivity:
- Absorption
- Incoherent scattering
- Roughness (10% of d_{layer}) (included in simulation)
- Interdiffusion?
- Limited coherence introduced by layer thickness fluctuations?

The SNS Magnetism Reflectometer



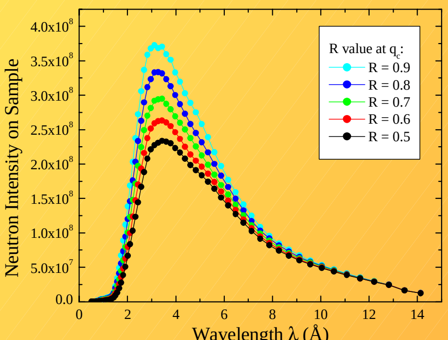
Neutrons from the cold liquid hydrogen moderator are guided to the sample position at an 18 m distance via a combination of a channel beam bender and a tapered neutron guide. The bender (length: 5 m) is used to minimize high-energy neutron background at the sample position. It deflects the useful part of the wavelengths distribution (λ > 1.5 Å) by 2° horizontally and feeds it into a 9 m long focusing section, which compresses the beam size to match a typical sample size of 25 mm by 25 mm. High-energy neutrons cannot follow this curvature and are scattered and absorbed by appropriate shielding. Neutrons scattered by the sample will be counted by a two-dimensional multidetector at a 19 m distance from the moderator. The wavelength is determined by time-of-flight. The neutron guide system of the instrument has been optimized by Monte Carlo simulations using the program IDEAS. m=3.5 supermirrors will be utilized for all guide surfaces.

"Experimental" set-up

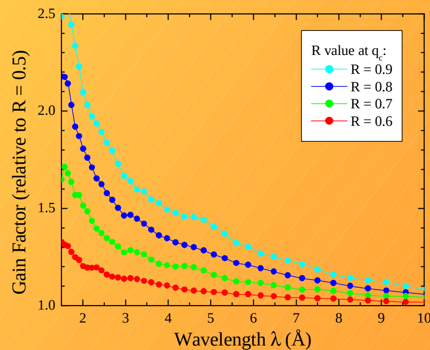


In order to reflect a realistic situation in which large guide gains can be expected, we calculated flux on sample for a low-resolution experiment. In this case a highly divergent beam can be utilized. In particular, we assume: 25 mm x 25 mm sample size, 20° incident angle, and 10% angular resolution. The latter is achieved by using a pair of slits with 50 cm distance from each other, which is located between the exit of the tapered guide and the sample position.

Performance gains



The intensities displayed in this figure have been integrated over 5% wide neutron wavelength bins. Note that the sharp wavelength cut-off at about 2 Å results from using the beam bender.



This figure shows the enhancement in flux-on-sample that may be achievable if supermirrors with higher reflectivity at q_c could be produced in large quantities. The intensity gain functions have been calculated by normalizing the flux values shown in the left figure relative to the R=0.5 data. It can be seen, that the short wavelength intensity in particular would be significantly increased.

Conclusions

- Flux enhancements as high as 40% may be achievable if R values of 0.8 could be reliably reached.
- Largest enhancement would be achieved for smallest wavelength.
- R&D money is well spent in this area because improvements on the SNS accelerator are much more expensive.

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* E-mail: CRehm@anl.gov; Phone/FAX: 1 630 252 5269/4163

** E-mail: MAgamalian@anl.gov; Phone/FAX: 1 630 252 6753/4163